Design of Speed and Power Control System for Wind Turbine with Reference Tracking Method

H. Ghanbari, H. Nikbakht, A. Zahedi, and M. Ghanbari

Abstract—This paper is focusing on designing a control system for wind turbine which can control the speed and output power according to arbitrary algorithm. Reference Tracking Method is used to control the turbine spinning speed in order to increase its output energy.

Keywords—Wind Turbine, Simulink, Reference Tracking Method.

I. INTRODUCTION

AN appropriate method for dynamic analysis of 2.5 MW nominal power Wind turbine is Lagrangian Dynamic Method. $NACA6412$ has been chosen for blade section and with Design Foil software which involves complete information of several blades section, the data are obtained. In the next step these data are sent to Solid Work software and cross section is drown and it will be 3D. This 3D model is so important because without complicated calculations, tensor of momentum of blade will be obtained.

For calculating total kinetic energy of wind turbine, the kinetic energy for rotation and transformation of blades and rotors should be calculated.

$$T_{total} = T_{tH} + T_{rH} + 3T_{tB} + 3T_{rB} \qquad (1)$$

The potential energy of rotor will be zero and it doesn't change when wind turbine works.

$$U_{total} = 0 \qquad (2)$$

According to values of kinetic and potential energies,

$$L = T_{total} - U_{total} \qquad (3)$$

Number of system's constrains is zero and equations of forced torque to the system is at the right side of equation.

H. Ghanbari is with the Department of Mechanical Engineering, Faculty of Engineering, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran (e-mail: ghanbari@iaufb.ac.ir)..

H. Nikbakht (e-mail: nickbakht@gmail.com).

A. Zahedi is with Department of Mechanical Engineering, Faculty of Engineering, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran (e-mail: zahedi@iaufb.ac.ir).

M. Ghanbari is a PhD student of University of South Australia, Adelaide, Australia (email: m_ghanbari_ir@yahoo.com).

Using these three equations rotor, blades and hub will be simulated and this model is ready for simulation process.

Tangent force on the blade at distance r from center of rotor will be:

$$dF_T = \frac{1}{2}\rho_w U_{rel}^2 (C_L \sin\eta - C_D \cos\eta)cdr \qquad (4)$$

In this equation, U_{rel} is relative velocity of wind, η is sum of α and β, β is angle of blade pitch, α is angle of attack, C_D and C_L are drag and lift coefficients, c is length of chord and ρ_w is density of air. If rotor has B Blades, aerodynamic torque of tangent force at distance r from rotation center will be:

$$dM_{Aero} = BrdF_T \qquad (5)$$

So:

$$dM_{Aero} = \frac{1}{2}B\rho_w U_{rel}^2 (C_L \sin\eta - C_D \cos\eta)crdr \qquad (6)$$

By integration from Eq. (6) along the blade, total torque will be obtained. [1]

It is assumed that the length of blade is approximately 40 meter and the value of chord when radius is 4.2 m will be 1.5 m and when radius is 40 cm chord will be 0.4 m.

By assuming linear variation of chord along the blade and by using other conditions:

$$c(r) = -0.03072625r + 1.62905027 \qquad (7)$$

So Eq. 7 by assuming $B = 3$:

$$M_{Aero} = \frac{3}{2}\rho_w \int_{4.2}^{40} U_{rel}^2 (C_L \sin\eta - C_D \cos\eta)c(r)rdr \qquad (8)$$

Regardless of aerodynamic torque at radius distance less than 4.2 m is ignored. By using Point Mark Method For lift and drag coefficients in Eq. (8) the equations will be obtained as follow:

$$C_L = -0.00089102564\alpha^3 + 0.01315384614\alpha^2 + 0.05650641032\alpha \qquad (9)$$

and,

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:7, No:3, 2013

$$C_D = 0.00005490196\alpha^2 + 0.00065098039\alpha + 0.0055 \quad (10)$$

By substituting above equations in Eq. (8) the aerodynamic model is ready.

By using Maple software and Simpson method the problem is solved with a good approximation. If air density is equal to 1.25 kg/m^3, the result is a function of $\dot{\varphi}, \beta$ and U_W. So this integral (Eq. (8)) is aerodynamic model of wind turbine and it is ready to use for simulation [2].

For an inductive generator, Synchronization velocity is defined:

$$\omega_s = \frac{4\pi f}{p} \quad (11)$$

f is voltage frequency of stator and p is number of stator's poles. Slip is defined as below:

$$n_s = \frac{\omega_s - \omega_r}{\omega_s} \quad (12)$$

ω_s is speed of Synchronization and ω_r is speed of rotor. [3]

For small slip:

$$T_e \cong \frac{E_t^2}{\omega_s R_2} n_s \quad (13)$$

T_e is electric torque, E_t is The venin voltage and R_2 is resistance of rotor coil.

$$T_e - T_L = J_e \frac{d\omega_r}{dt} \quad (14)$$

In the above equation T_L, J_e and ω_r are mechanical torque, Rotational inertia and Rotational speed of the generator rotor.

Finally electrical output power for three phases in this generator is presented by Eq. (15) :

$$P_e = 3 E_t I_2 \cos\phi \quad (15)$$

I_2 is current of stator coil and ϕ Is the phase difference between voltage and current. Finally from equations 12, 13, 14 a simple model is obtained and it will be used for calculation and simulations.

Simulink is one of the most powerful software for this purpose, After that we have the model and by using inputs from other software Simulink can solve the problem [4].

II. REFERENCE TRACKING METHOD

To control wind turbine a pitch method is used in this paper. In this method each blade of turbine can rotate around its axis. Supervised by a computer blade angle is changed each moment to gain the maximum power.

In Fig. 1 you can see variation of power against speed of rotor. At each constant wind velocity with variation of rotor speed, power increases then at a specific speed the value of power will be maximum. After that with increase of rotor speed, power decreases. So we can find an optimum rotor speed for each wind speed.

As a good suggestion, It's better if turbine always works at speed that we have maximum amount of power. So in low speed, turbine must follow the maximum power. From low until average speed turbine has to work in nominal speed, but in high speed the power must be lower than nominal power and speed of rotor must decrease with a controller.

We can define three working area for turbine using Reference Tracking Method. In this definition for each wind speed a certain value for rotor speed is defined and controller checks this.
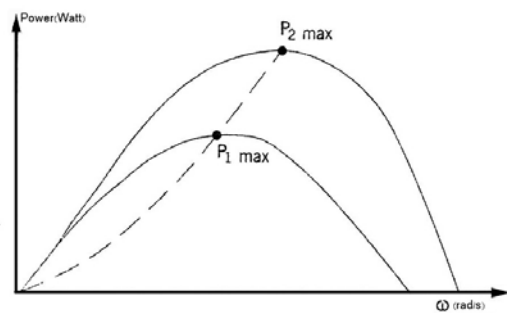

Fig. 1 Variation of power with rotor speed

III. DESIGN OF SPEED CONTROLLER

Working area of wind turbine is shown in Fig. 2. The best area is "a", but according to the break in the curve "b" and "c' are suggested. So for "b":

$$\dot{\psi}_{ref} = 0.9805714241\times10^{-5}U_W^5 - 0.9134285681\times10^{-3}U_W^4 + 0.3300380942\times10^{-1}U_W^3 \ (20) - 0.5705357130U_W^2 - 4.645061897U_W - 10.24714284$$

$$(16)$$

Fig. 2 Working area of wind turbine

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:7, No:3, 2013
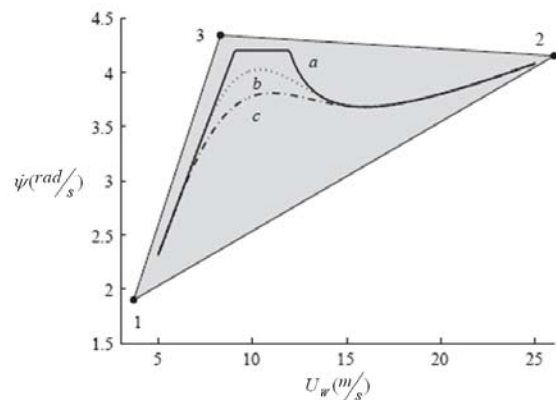
The system is shown in Fig. 3. Every moment the speed of rotor is compared with defined speed and if there is an error required voltage should send to motor and the pitch angle changes, also the speed of rotor will change. In this problem we used PID controller with $K_P = 8500$، $K_I = 95$ و $K_D = 5610$. Fig. 4.
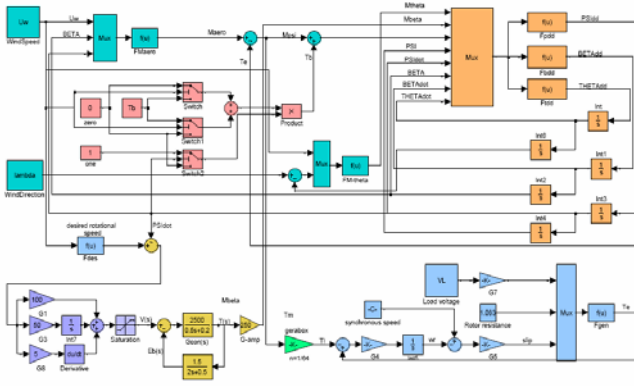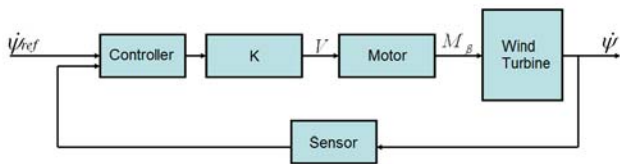

Fig. 3 Wind turbine modeling

Fig. 4 PID controller

IV. YAW CONTROLLER

To control the direction of wind turbine against wind, yaw controller is used. Every moment by changing wind direction a return torque changes the direction of turbine, Fig. 5.
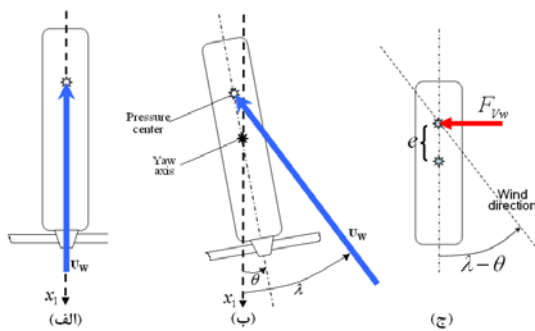

Fig. 5 Yaw controller

V. CUT-IN & OUT SPEED

While the wind speed is not enough for working, breaks stop the turbine and when wind speed is high, wind turbine will stop. Speeds for Cut-in and Cut-out are 5 and 25 m/s^2 (Fig. 6).
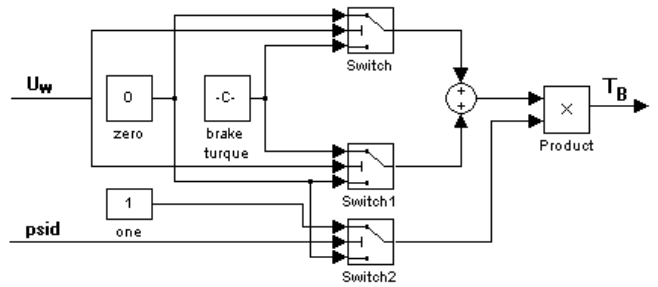

Fig. 6 Cut-in and Out speeds

VI. RESULTS

To solve this problem we assume an optional condition. For example if wind speed is constant and equal to 12.5 m/s^2 and load voltage is variable, in Fig. 7 (a), (b), (c) and (d) you can see the results.

Diagrams of load voltage, error percentage, electric power and yaw error are shown. In this case speed error is ± 0.02 And yaw error is $\pm 0.001\, rad$. Also the results for a variable speed in comparison to with constant speed shows 3.47 percentage increase in energy absorbing from wind.
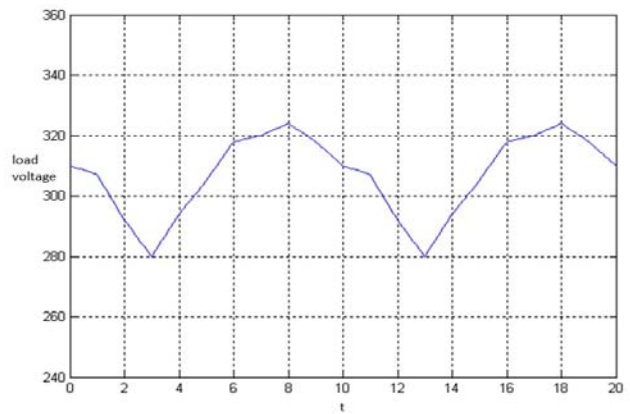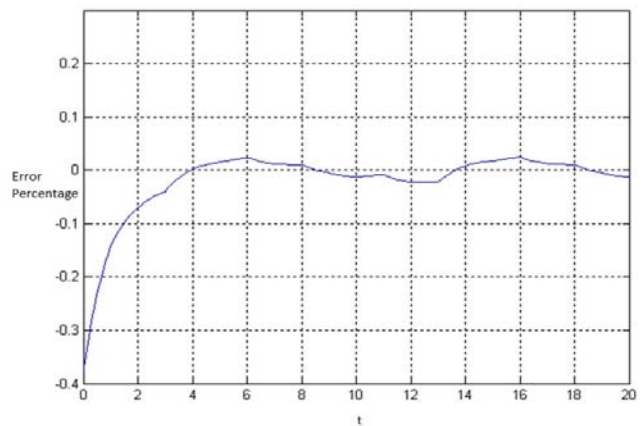

Fig. 7 (a) Diagrams of load voltage
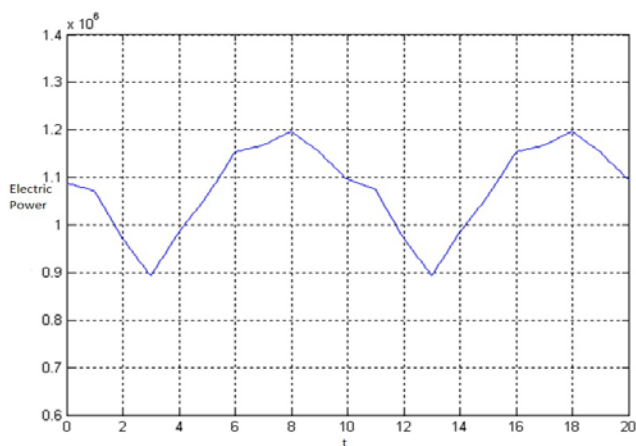

Fig. 7 (b) Diagrams of error percentage

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
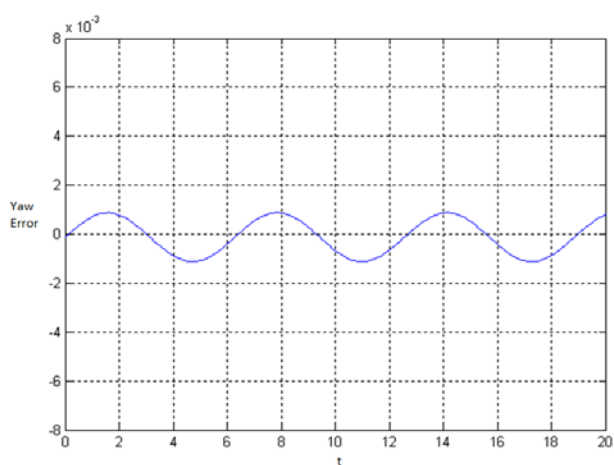Vol:7, No:3, 2013

Fig. 7 (c) Diagrams of electric power

Fig. 7 (d) Diagrams of yaw error

REFERENCES

[1] Manwell, J. F., McGowan, J. G., and Rogers, A. L. "Wind energy explained Theory design and Application". John Wiley & Sons, Ltd., 2002.

[2] Potel, M. R. "Wind and solar power systems". CRC Press LLC., 1999.

[3] Bianchi, F. D., Mantz, R. J., and Christiansen C.F. Gain scheduling "control of variable-speed wind energy conversion systems using quasi-LPV models". Control Engineering Practice, 13: 247–255, 2005 .

[4] H. Ghanbari, H. Nikbakht, A. Zahedi, M. Ghanbari, "Design of Speed and Power Control System for wind Turbine with Reference Tracking Method", Word Academy of Science Engineering and Technology.